Journal of the Lepidopterists' Society
47(4), 1993, 331–337

DIFFERENCES IN SEASONAL PERFORMANCE OF TWENTY-SIX STRAINS OF SILKWORM, *BOMBYX MORI* (BOMBYCIDAE)

Additional key words: sericulture, cocoon yield, silk production.

Commercial exploitation of the mulberry silkworm (*Bombyx mori* L., Bombycidae) results in the production of 10,000 metric tons of raw silk in India annually (Thomas 1991). There are approximately 2000 different strains of *Bombyx mori* used in silk production (Reddy 1986). Twenty-one characters of this species are recognized as contributing to silk yield quantitatively or qualitatively (Chatterjee et al. 1990). These are: 1) fecundity; 2) hatching percentage; 3) missing percentage of young age larvae (i.e., early larval survival); 4) missing percentage of late age larvae (late larval survival); 5) total larval duration (i.e., rearing period); 6) fifth instar duration; 7) cocoon yield number per 10,000 larvae brushed [Silkworm eggs will be either on an egg sheet or in loose form. Brushing is the process of carefully separating the newly hatched larvae from the empty egg shells or egg sheets, and transferring them to the rearing trays with the help of a smooth brush.]; 8) cocoon yield (weight per 10,000 larvae brushed); 9) pupation rate; 10) single cocoon weight; 11) single shell weight; 12) shell ratio (i.e., ratio of single shell weight to single cocoon weight expressed in percentage); 13) mature larval body weight; 14) floss percentage [Floss is the foundation layer of the cocoon with entangled filaments from which a continuous silk filament cannot be obtained.]; 15) single cocoon filament length; 16) single cocoon filament weight; 17) filament size; 18) reelability percentage; 19) raw silk percentage; 20) neatness; and 21) boil-off ratio [Silk thread is reeled from the cocoons by boiling them in water so that the gummy materials are dissolved and the silk filament can be reeled without any breaks. The term is used in silk industry to classify the grade of raw silk with respect to reeling and weaving.]. While some of these characters are heritable, others are determined by environmental factors.

The domestic and international demand for silk always has been greater than can be met. In India, the average silk yield from indigenous strains of silkworms is around 30 kg/100 dfl (dfl = disease-free laying; one dfl equals approximately 500 eggs with an average 80% hatching, i.e., 400 worms). By contrast, in Japan the average yield is 60 kg/dfl. If the yield in India could be increased to 45 kg/dfl, overall silk production would increase by 50% (Thiagarajan et al. 1991). This may be achieved by rearing silkworm strains most suited for particular seasons. However, in India this practice is not employed. As a result, failures in rearings frequently lead to crop losses and frustration among farmers. To solve this problem and achieve maximal harvest, it is essential to select a few superior strains of silkworm in relation to seasonal performance. In Japan, there are 19 strains suitable for spring rearing (May–June) and 22 strains suitable for summer (July–August) and autumn (September–October) rearings (Shimizu & Tajima 1972). The purpose of our study was to evaluate the performance of different strains of silkworm available to us in relation to their performance in spring, summer, and autumn.

Materials and methods. Rearing experiments were conducted in the spring, summer, and autumn for three years (1989–1991) at the Regional Sericultural Research Station, Coonoor, in the Nilgiri Hills of Western Ghats, India. All of the twenty-six strains of silkworm available to us (Table 1) were reared in a randomized block design. Each group evaluated consisted of the larvae from a single laying by an individual female moth. All the larvae were retained until spinning. Each experimental tray was placed in a rearing stand; the positions of the trays were changed regularly three to four times a day to reduce effects of environmental factors. Standard techniques for rearing silkworms (i.e., temperature 23–28°C, relatively humidity 79–90%, and 12/12 h dark/light ratio) were applied (Krishnaswami 1978). Duration of experimental rearings was 26 days for summer, 27 days for spring, and 28 days for autumn, with three replications of each strain.

Observations were made on five characters of economic importance: 1) cocoon yield (number per 10,000 larvae brushed); 2) single cocoon weight; 3) single shell weight; 4) shell ratio; and 5) filament length. Data were analyzed according to Lush (1954) and Kempthorne (1957).

TABLE 1. Salient characteristics of twenty-six silkworm strains used in the study.

Sl no.	Strain	Geographical origin	Larval marking	Cocoon color/cocoon shape/shell grains/floss amount
1	C108	China	Plain	White/oval/ordinary/less
2	C120	China	Plain	White/oval/medium/less
3	Dong306	China	Plain	White/short oval/medium/more
4	NN6D	China	Plain	White/oval, short oval/ordinary/less
5	J1 (M)	Japan	Marked	White/elongated constricted/ordinary/less
6	J2 (P)	Japan	Plain	White/elongated oval/medium/less
7	J2 (M)	Japan	Marked	White/deeply constricted/medium/less
8	JC2 (P)	Japan	Plain	White/oval/medium/less
9	CJ3 (P)	Japan	Plain	White/oval/medium/less
10	M2	Japan	Plain	White/slightly constricted/medium/less
11	SPC1	Japan	Plain	White/oval, short oval/medium/less
12	SPJ1	Japan	Marked	White/slender constricted/medium/less
13	SPJ2	Japan	Marked	White/slender constricted/medium/less
14	N4	Japan	Marked	White/constricted like dumbbell/medium/less
15	J122	Japan	Plain	White/oval, mildly constricted/medium/less
16	14M	Japan	Marked	White/dumbbell/medium/less
17	36 (PC)	Japan	Plain	White/dumbbell/medium/less
18	SN1*	Japan	Plain/marked	White/dumbbell/medium/less
19	NJ1*	Japan	Plain/marked	White/dumbbell/medium/less
20	JA1	India	Marked	White/dumbbell/medium/less
21	JB2	India	Marked	White/dumbbell/medium/fine/less
22	SH2	India	Plain	White/oval/fine/less
23	NB1	India	Plain	White/oval/medium/less
24	European	France	Plain	White/dumbbell/medium/less
25	JZH (PO)	Brazil	Plain	White/oval/medium/less
26	JZH (MC)	Brazil	Marked	White/constricted like dumbbell/medium/less

* Sex-limited strains. In a given strain, plain larvae are males and marked ones are females.

Analysis of variance of the five characters for twenty-six strains in three seasons and the strains/season interaction were evaluated as described by Pershad et al. (1986). A simple method for making a decision on each character based on least significant difference as described by Thiagarajan et al. (1993) was followed for each character for ranking of the races. The population means were arranged in groups based on t-test (and l.s.d.). The topmost group containing populations with the highest means was given a score 1, the next best a score of 2, and so on. If 'k' is the number of groups for a particular character, the populations in group 1 were given a score = 1/k, those in group 2 a score = 2/k, and so on to obtain standardized scores across the characters. The individual scores for each character were added up to provide a total score for each population. The populations then were ranked in descending order of the numerical values of total scores. The method consists of the following steps:

1. The performance of each character as demonstrated by its mean value in the particular entry or season and a score (actual score) is allotted to that character. A high mean value will get a score of 1; moderate value 2; low value 3 and so on.
2. The actual score assigned for a particular character is converted into a standard score by dividing actual score obtained with the number of scores applied. For example, in ERR character we used a total of 4 scores. Hence, the standard score will be "actual score/4."
3. A score or rank Si is obtained for each entry [there are 4 entries in each race, which stand for (i) summer, (ii) spring, (iii) autumn and (iv) the average of three seasons] by multiplying standard score with the number of characters (which is 5 in this study).

Si = sij (where j = number of characters)

To demonstrate this method, here are the performance scores for 14 M in the spring season:

Character	Actual score	Standard score
ERR	1	1/4
Single cocoon weight	4	4/4
Single shell weight	1	1/4
Shell ratio	1	1/4
Filament length	4	4/4

Out of 5 characters, race 14 M received score 1 in 3 characters.

Results and discussion. The average rearing performance together with the least significant difference values of each character of the twenty-six strains of silkworm in spring, summer, and autumn seasons during three years is shown in Table 2. Analysis of variance, i.e., the mean squares for all the five characters, are given in Table 3.

Based on least significant difference values, the following strains are found to be most suitable to rear during particular seasons: European and 14 M (spring), JC2P (summer), M2 (autumn). These strains performed well for most of the characters of economic importance, especially cocoon yield. However, as illustrated in Table 2, the remaining strains also are useful for one or more characters.

The results of season specific performance of different strains with respect to characters like cocoon yield, single cocoon weight, single shell weight, shell ratio, and filament length noted in this study are in agreement with earlier reports on this subject (Venugopala Pillai 1979, Pershad et al. 1986, Thiagarajan et al. 1993). The results of the analysis of variance showed significant difference at the 1% level between the three seasons, twenty-six strains, and strains/seasons interaction for all the five characters studied. This indicates

TABLE 2. Mean values for five characters in twenty-six strains of silkworm in spring, summer and autumn seasons.

1 Sl no.	2 Strain	3 Season	4 Cocoon yield/ 10,000 larvae brushed (no.)	5 Single cocoon weight (g)	6 Single shell weight (g)	7 Shell ratio (%)	8 Filament length (m)
1	C108	Spring	8100	1.80	0.32	17.78	840
		Summer	9783*	1.78	0.25	14.05	821
		Autumn	8867	1.83	0.31	16.94	933
2	C120	Spring	8975	1.52	0.32	21.05*	935
		Summer	8500	1.47	0.28	19.05	929
		Autumn	7750	1.54	0.34	22.08*	1012
3	Dong306	Spring	9500*	1.68	0.26	15.48	889
		Summer	9700*	1.69	0.31	18.34	994
		Autumn	7900	1.06	0.23	21.70*	1042
4	NN6D	Spring	5861	1.45	0.27	18.62	976
		Summer	8417	1.67	0.28	16.77	845
		Autumn	9350*	1.62	0.28	17.28	940
5	J1 (M)	Spring	8475	1.62	0.31	19.14	928
		Summer	8567	1.74	0.33	18.97	1193*
		Autumn	9600*	1.60	0.32	20.00	987
6	J2 (P)	Spring	8475	1.70	0.37*	21.77*	1035
		Summer	8567	1.89	0.33	17.46	1018
		Autumn	9150	1.76	0.34	19.32	832
7	J2 (M)	Spring	8550	1.92	0.38*	19.79	1060
		Summer	9500*	1.78	0.30	16.85	890
		Autumn	9200	1.71	0.32	18.71	967
8	JC2 (P)	Spring	9475*	1.75	0.36	20.57	1077
		Summer	9217*	1.69	0.37*	21.89*	1192*
		Autumn	8550	2.01	0.42*	20.90*	1102
9	CJ3 (P)	Spring	8550	1.75	0.37*	21.14*	1194*
		Summer	9317*	1.77	0.34	19.21	1079
		Autumn	8388	2.13*	0.39*	18.31	1059
10	M2	Spring	9525*	1.45	0.29	20.00	1003
		Summer	9517*	1.66	0.33	19.88	1079
		Autumn	9750*	2.06*	0.43*	20.87*	1191*
11	SPC1	Spring	7950	0.50	0.30	20.00	1063
		Summer	8350	1.73	0.30	17.34	900
		Autumn	9250*	1.62	0.28	17.28	1102
12	SPJ1	Spring	9500*	1.65	0.30	18.18	1030
		Summer	8333	1.84	0.36	19.57	872
		Autumn	9000	1.63	0.31	19.02	1125
13	SPJ2	Spring	7275	1.70	0.30	17.65	963
		Summer	8400	1.72	0.35	20.35	928
		Autumn	9300*	1.63	0.37*	22.70*	1177
14	N4	Spring	6888	1.65	0.30	18.18	994
		Summer	6467	1.41	0.28	19.86	1067
		Autumn	5067	1.62	0.38*	23.46*	1229*
15	J122	Spring	9075	1.76	0.32	18.18	923
		Summer	8883	1.95	0.31	15.90	938
		Autumn	9550*	1.77	0.31	17.51	946

TABLE 2. Continued.

1 Sl no.	2 Strain	3 Season	4 Cocoon yield/ 10,000 larvae brushed (no.)	5 Single cocoon weight (g)	6 Single shell weight (g)	7 Shell ratio (%)	8 Filament length (m)
16	14M	Spring	9200*	1.75	0.40*	22.86*	1254*
		Summer	8900	1.84	0.38*	20.65	1044
		Autumn	8321	1.74	0.36	20.69	1147
17	36PC	Spring	8762	1.73	0.38*	21.97	1276*
		Summer	7567	1.86	0.35	18.81	1033
		Autumn	8433	2.05	0.37*	18.05	1039
18	SN1	Spring	6025	1.80	0.34	18.89	956
		Summer	8867	1.79	0.31	17.32	949
		Autumn	7917	1.68	0.35	20.83	1242*
19	NJ1	Spring	5825	1.83	0.37	20.22	11.07
		Summer	8917	1.86	0.37	19.89	1170
		Autumn	8450	2.05	0.41	20.00	1240*
20	JA1	Spring	4425	1.67	0.35	20.10	1202*
		Summer	9633*	1.67	0.32	19.16	1128
		Autumn	8700	2.04	0.41*	20.10	1111
21	JB2	Spring	9565*	1.78	0.32	17.98	1007
		Summer	8383	2.12*	0.40*	18.87	1175
		Autumn	8347	1.97	0.41*	20.81	1164
22	SH2	Spring	7150	1.68	0.36	21.43*	1285
		Summer	7517	1.85	0.38	20.54	1271
		Autumn	6505	2.09*	0.40*	19.14	1101
23	NB1	Spring	9575*	1.75	0.33	18.86	1023
		Summer	9633*	1.90	0.31	16.32	838
		Autumn	9450*	1.67	0.30	17.96	967
24	European	Spring	9240*	1.86	0.39*	20.97*	1187*
		Summer	9167	1.75	0.31	17.71	1064
		Autumn	8600	1.96	0.39*	19.90	1075
25	JZH (PO)	Spring	9100	1.62	0.30	18.52	1151
		Summer	9517*	1.76	0.30	17.05	993
		Autumn	7650	2.16*	0.39	18.06	1087
26	JZH (MC)	Spring	9200*	1.70	0.29	17.06	863
		Summer	8450	1.99	0.38*	19.10	1059
		Autumn	8150	1.99	0.38*	19.10	1129
	LSD at 5% level		583	0.10	0.06	2.62	101

* Significant at 5% level.

that not only heredity but also environmental factors influence the performance of a given strain for the characters studied.

In addition to the leaf quality of mulberry in different seasons, physical factors such as temperature and relative humidity (RH) also greatly influence the growth of silkworms (Gabriel & Rapusas 1976). First and second instars reared at 26–28°C temperature and 80–90% RH are healthier in later stages (third, fourth and fifth instars). Temperature, RH, and ventilation during the spinning of silkworms influence the quality of cocoon. The length of silk filament also may vary in the given strain in different seasons (Ueda et al. 1969). Recent experiments have shown that physical properties such as cocoon

TABLE 3. Mean squares for five characters in *Bombyx mori* L.

Source of variation	df	Cocoon yield	Single cocoon weight	Single shell weight	Shell ratio	Filament length
Seasons	2	534,050* F = 4.63	0.288** F = 12.00	0.011** F = 11.00	38.71** F = 15.42	8780** F = 7.80
Strains	25	548,104** F = 4.76	0.144** F = 6.00	0.009** F = 9.00	14.14** F = 5.59	8505** F = 7.55
Strains × seasons	50	570,470** F = 4.95	0.161** F = 6.71	0.008** F = 8.00	30.28** F = 12.06	7971** F = 7.08
Error	206	115,231	0.024	0.001	2.51	1126

* and ** Significant at 5% and 1% level, respectively. df = degrees of freedom.

weight, shell weight, and filament length will be optimal when mature *Bombyx mori* are kept at 21–24°C temperature and 67% RH.

Since domestication of silkworm, mankind has been interested in breeding silkworm varieties that produce greater quantities of silk. Silkworm breeders in sericulturally advanced countries like Japan and South Korea have always utilized season specific silkworm strains. Mano et al. (1991) recommended the hybrid N147 × C145, with high cocoon shell weight and long filament length, as a suitable silkworm race for the spring season. Similarly, Sohn et al. (1990) have produced a hybrid silkworm variety named Samkwang-jam suitable for summer and autumn rearings with high silk yielding ability.

To obtain the best cocoon crop quantitatively and qualitatively, a particular strain should be reared during the season in which the environmental conditions are most favorable for its genotype. Knowing that variation caused by the environment can be produced in the offspring by repeating the environmental treatments, which produced them in the parent, we can exploit successfully the cocoon crops from 14 M and European in spring, JC2P in summer, and M2 in autumn seasons.

The authors express their deepest gratitude to R. K. Datta, Director, Central Sericultural Research and Training Institute, Mysore, India, for constant encouragement and interest in the present study. Thanks are also due to Mr. S. Sekar, stenographer of this station, for typing the manuscript.

LITERATURE CITED

CHATTERJEE, S. N., C. S. NAGARAJ & K. GIRIDHAR. 1990. An approach to silkworm breeding, pp. 11–16. *In* Datta, R. K. (ed.), Workshop on biometrical genetics proceedings. Central Sericultural Research and Training Institute, Mysore, India.

GABRIEL, B. P. & H. R. RAPUSAS. 1976. The growth and development of *Bombyx mori* (L.) at different leaf maturity and variety of mulberry. Philippines Agricul. 60:130–146.

KEMPTHORNE, O. 1957. An introduction to genetic statistics. Wiley, New York. 264 pp.

KRISHNASWAMI, S. 1978. New technology of silkworm rearing. Central Sericultural Research and Training Institute Bulletin 2:1–10.

LUSH, J. L. 1954. Chapter 8. Heredity and environment, pp. 90–102. *In* Lush, J. L. (ed.), Animal breeding plans. Iowa State Univ. Press, Ames.

MANO, Y., M. OHYANAGI, K. NAGYASU & A. MURAKAMI. 1991. Breeding of sex limited larval marking silkworm race, N147 × C145. Bull. Natl. Inst. Seri. Entomol. Sci. 2:1–29.

PERSHAD, G. D., R. K. DATTA, H. V. VIJAYAKUMAR, S. K. BHARGAVA & M. S. JOLLY. 1986. Performance of some multivoltine races of *Bombyx mori* L. Sericologia 26: 295–301.

REDDY, G. S. 1986. Genetics and breeding of silkworm, *Bombyx mori* L., pp. 70–80. *In* Boraiah, G. (ed.), Lectures on sericulture. Suramya Publ., Bangalore, India.

SHIMIZU, M. & Y. TAJIMA. 1972. Silkworm races suitable for spring, summer and autumn

rearing, pp. 304–307. *In* Shimizu, M. & Y. Tajima (eds.), Handbook of silkworm rearing. Agric. Tech. Man. 1. Fuji Publ. Co., Ltd., Tokyo, Japan.
SOHN, K. W., K. W. HONG, S. J. HWANG, K. S. RYU, K. M. KIM, S. R. CHOI, K. Y. KIM & S. P. LEE. 1990. Breeding of Samkwangjam, a F1 hybrid silkworm variety suitable for summer–autumn rearing with the high silk yielding ability and a sex-limited parent. Res. Rep. Rural Dev. Adm. 32:1–16.
THIAGARAJAN, V., S. S. SINDAGI, S. AMARNATH & N. N. NAGABHUSANA RAO. 1991. Need for a study on silkworm hybrids in different seasons. Indian Silk 30:43–45.
THIAGARAJAN, V., S. K. BHARGAVA, M. RAMESH BABU & B. NAGARAJ. 1993. Performance of bivoltine breeds of silkworm (*Bombyx mori*) under high altitude conditions. Sericologia. In press.
THOMAS, P. S. S. 1991. Sericulture may revolutionise Indian economy. A report from the United News of India. N.S.P. Newsletter 1(9):4–5. Central Silk Board, Bangalore, India.
UEDA, S., R. KIMURA & K. SUZUKI. 1969. Studies on the growth of silkworm, *Bombyx mori* (L). II. The influence of the rearing conditions upon larval growth, productivity of silk substances, eggs and boiled off loss in the cocoon shell. Bull. Seri. Expt. Stn. Japan 23:290–293.
VENUGOPALA PILLAI, S. 1979. Growth studies in silkworm *Bombyx mori* (L.) with special reference to its economic characters. Ph.D. Thesis, University of Kerala, India, pp. 41–56.

V. THIAGARAJAN, S. K. BHARGAVA, M. RAMESH BABU, AND B. NAGARAJ, *Regional Sericultural-Research Station, P.O. Box 21, Coonoor 643 101, India.*

Received for publication 1 July 1992; revised and accepted 1 May 1993.